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Review Article

Amaranthus tricolor: A Nutrient-Dense Functional Food with Promising Therapeutic Potential

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ABSTRACT

Amaranthus tricolor, or red amaranth, is a nutritionally dense leafy vegetable with broad medicinal and dietary applications, commonly consumed in tropical and subtropical regions. Traditionally, it has been used in Siddha and Ayurveda to address a range of conditions including diarrhea, dysentery, bronchitis, and hemorrhagic ailments. Recent studies emphasize its diverse pharmacological potential, showcasing its antimicrobial, hepatoprotective, anti-diarrheal, neuroprotective, cardioprotective, anti-melanin, anthelmintic, antibacterial, anticancer, anti-nociceptive, and anti-inflammatory activities. These therapeutic properties are largely attributed to the plant's rich profile of phytochemicals, including phenolics, flavonoids, alkaloids, betacyanins, and amaranthine. In terms of nutritional value, *A. tricolor* is an exceptional source of essential nutrients like vitamins A and C, carotenoids, calcium, iron, and several key minerals, presenting an advantageous profile over common greens such as lettuce and spinach. The plant's antioxidant activity, critical for neutralizing reactive oxygen species (ROS), has implications for reducing oxidative stress and supporting the prevention of aging and chronic diseases. Additionally, research indicates that salt-stressed *A. tricolor* plants exhibit elevated antioxidant levels, suggesting a resilience that allows cultivation under diverse environmental conditions. Despite these promising attributes, specific bioactive compounds contributing to its extensive health benefits remain underexplored. This study aims to consolidate findings on the nutritional composition, antioxidant potential, and extensive pharmacological activities of *A. tricolor*, underscoring its value as an economically viable, nutrient-dense crop with considerable therapeutic applications and encouraging further research.

Introduction

Amaranthus tricolor Linn, commonly known as red amaranth, is a widely popular and nutritionally rich plant, particularly in Central America, where it has been cultivated alongside staple crops like corn and beans. Its leaves, stems, and seeds are edible and are consumed both raw and cooked, offering a substantial nutritional profile.[1] Known for its resilience to varying environmental conditions, *A. tricolor* is among the most easily cultivated plants, with over 800 species in the *Amaranthus* genus. Specifically, *A. tricolor* has a long history in Siddha and Ayurvedic medicine, traditionally used to treat hemorrhagic colitis, diarrhea, bronchitis, menorrhagia, cough, and intestinal hemorrhage. *A. tricolor* leaves were found to contain 41 metabolites, including amino acids, phenolic acids, and fatty acids, as well as rare bioactive betacyanin pigments, which are uncommon in nature. These compounds have demonstrated a wide range of pharmacological properties like antioxidant, antimicrobial, neuroprotective, anti-inflammatory, anticancer, and hepatoprotective effects. [2-5]

Interest has grown in antioxidants derived from natural sources that counteract oxidative stress, a contributing factor to aging and many chronic diseases. Antioxidants act by quenching reactive oxygen and nitrogen species and, in some cases, by chelating metal ions or inhibiting

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oxidative enzymes. The evaluation of antioxidant activity is typically conducted through diverse methods, each reflecting different mechanisms of action.[6,7]

As a leafy vegetable, *A. tricolor* is a rich source of essential nutrients, including amino acids, vitamins, minerals (such as iron, calcium, magnesium, potassium, and zinc), pigments, carotenoids, phenolic, and flavonoids. Compared to lettuce, it provides significantly more vitamins A, C, calcium, and iron. Minerals, which constitute 4 to 6% of the human body, play vital roles in tissue structure, cellular metabolism, and acid-base balance. Red amaranth leaves are particularly rich in protein, dietary fiber, fats, and carbohydrates, and also contain high levels of betalains, betaxanthins, and betacyanins. Additionally, these leaves are packed with bioactive compounds, including alkaloids, glycosides, phenolic acids, flavonoids, amaranthine, and tannins.[8-12]

The bioactive compounds in *A. tricolor*, such as phenols, flavonoids, and pigments, are widely available from natural sources and present promising alternatives for disease prevention. As a readily available, affordable source of nutrients, *A. tricolor* plays a crucial role in the dietary practices of developing countries.[13-15]

Therapeutic Potential of *A. tricolor*

Antioxidant activity

The antioxidant properties of the methanol extract and its various fractions of *A. tricolor* L. were evaluated. Among these, the ethyl acetate fraction exhibited the highest antioxidant potential, as demonstrated by its 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical-scavenging activity. Its performance surpassed that of the positive control, butylated hydroxyanisole (BHA). In addition, the ethyl acetate extract showed a reducing power, indicating its strong electron-donating capacity. The extract also demonstrated a significant ability to attenuate reactive oxygen species production in a dose-dependent manner, indicating its potential for protecting cells from oxidative stress. These results highlight the significant antioxidant properties of *A. tricolor*, which may have therapeutic implications for managing oxidative stress-related conditions. Various fractions of the ethyl acetate extract led to the isolation of three key bioactive compounds kaempferol, quercetin, and gallic acid are obtained from various fractions of the ethyl acetate extract, which are likely responsible for the observed antioxidant effects, indicating their potential as natural antioxidants for health benefits. [16]

Antimicrobial activity

The antimicrobial activity of methanol extract and its various fractions *A. tricolor* was evaluated against various fungal and bacterial strains, including *Aspergillus awamori*, *Cladosporium herbarum*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Bacillus subtilis*, *Penicillium oxalicum*, *Aspergillus niger*, and *Escherichia coli*. The results demonstrated that the antimicrobial efficacy of *A. tricolor* varied based on the solvent fraction and the specific microorganism tested. Notably, the ethyl acetate extract exhibited significant antimicrobial activity against all tested fungal and bacterial strains. However, the butanol fraction demonstrated the highest antibacterial efficacy, particularly against *S. aureus* and *E. coli*. These findings suggest that *A. tricolor* contains bioactive compounds with broad-spectrum antimicrobial properties.[17]

Hepatoprotective activity

A. tricolor, both aqueous and ethanolic extracts, have demonstrated significant hepatoprotective effects against chemically induced liver damage in albino rats. In particular, the aqueous root extract protected against paracetamol-induced hepatotoxicity, while the ethanolic leaf extract effectively mitigated carbon tetrachloride (CCl_4)-induced liver damage. Pre-treatment with the *A. tricolor* extracts significantly reduced serum levels of liver enzymes, including serum glutamic oxaloacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), alkaline phosphatase (ALP), and total bilirubin, indicating enhanced liver function. Histopathological analysis corroborated these findings, revealing diminished hepatic damage and preserved liver architecture, comparable to the effects observed with silymarin, a standard hepatoprotective agent. [18]

In a separate experiment, ATE administered over three weeks demonstrated comparable hepatoprotective effects against CCl_4-induced liver damage. ATE treatment led to significant reductions in serum enzyme levels, including SGOT, SGPT, gamma-glutamyl transferase ALP, bilirubin, cholesterol, LDL-C, VLDL-C, triglycerides, and malondialdehyde, a marker of oxidative stress. Furthermore, *A. tricolor* increased non-protein sulfhydryl and total protein levels in liver tissue, suggesting enhanced antioxidant defenses and protein restoration. The histopathological evaluation also showed notable improvements in liver tissue structure. The hepatoprotective effects of both extracts are attributed to their antioxidant properties, which alleviate oxidative stress and mitigate toxin-induced liver injury. These findings underscore the potential of *A. tricolor* as a natural hepatoprotective agent for liver disease management.

Anti-diarrhoeal potential

The anti-diarrheal potential of *A. tricolor* ethanolic and ethyl acetate leaf extracts was investigated through castor oil-induced diarrhea and gastrointestinal motility tests in rats. *A. tricolor* showed a significant reduction in diarrhea severity and decreased intestinal motility, evidenced by a shorter distance traveled by activated charcoal in the intestine. These extracts exhibited a level of efficacy comparable to that of loperamide, a widely used anti-diarrheal medication known for its ability to slow

intestinal transit, reduce colonic flow rates, and diminish overall motility. Additionally, the extracts markedly inhibited castor oil-induced enteropooling, suggesting an anti-secretory and spasmolytic effect that helps reduce fluid accumulation in the intestines. The findings suggest that *A. tricolor* acts through dual mechanisms—by slowing intestinal movement and reducing water and electrolyte secretion—leading to relief from diarrhea. The observed effects may be attributed to compounds within the extracts that exert anti-cholinergic and spasmolytic activity, similar to the action of atropine, which also reduces propulsive movement in the intestines. Consequently, *A. tricolor* appears to be a promising natural source of anti-diarrheal agents, potentially beneficial for treating acute and chronic diarrhea. Further studies are recommended to isolate and characterize the bioactive components and fully understand the mechanisms underlying the anti-diarrheal effects of *A. tricolor* extracts. [19]

Neuroprotective activity

The neuroprotective potential of hydroalcoholic leaf extract of *A. tricolor* was investigated using scopolamine-induced and other neuro-disorder rat models. The extract demonstrated significant improvements across various neuroprotective parameters, including enhanced anti-stress, nootropic, and anti-cataleptic activities, all observed in a dose-dependent manner. It significantly reduced swimming time and increased anoxia tolerance, suggesting anti-stress effects. Biochemical markers also improved, with reductions in glucose and cholesterol levels and beneficial modulation of hematological parameters, including lowered white and red blood cell counts. In cognitive tests, *A. tricolor*-treated rats demonstrated improved learning and memory retention. In the plus-maze acquisition test, the treated rats exhibited reduced latency, indicating better memory recall and learning ability, as compared to the scopolamine-induced amnesia control group. Furthermore, in the Morris water maze test, used to evaluate spatial learning and memory, both the *A. tricolor* extract group and the standard treatment group demonstrated shorter exit delays, highlighting the extract's cognitive enhancing properties. These findings suggest that *A. tricolor* extract offers significant neuroprotective benefits, potentially safeguarding against memory loss and cognitive decline in neurodegenerative conditions. [20]

Cardioprotective activity

The cardioprotective potential of *A. tricolor* was evaluated in ovariectomized rats subjected to isoproterenol (ISO)-induced myocardial injury, a model designed to mimic post-menopausal cardiac stress. The administration of ISO markedly increased oxidative stress markers such as malondialdehyde, nitric oxide, and advanced protein oxidation products, while significantly decreasing superoxide dismutase (SOD) activity, indicating severe myocardial damage. Treatment with an ethanolic extract of *A. tricolor* and atenolol effectively counteracted these adverse effects. Both interventions restored antioxidant enzyme levels and reduced oxidative stress markers, demonstrating the protective effects of *A. tricolor* against ISO-induced myocardial injury. The study further demonstrated a reduction in elevated AST, ALT, and CK-MB enzyme activities, accompanied by the normalization of uric acid and creatinine levels in *A. tricolor*-treated groups. Histopathological analysis revealed that *A. tricolor* treatment alleviated inflammatory cell infiltration, fibrosis, and iron deposition in cardiac tissue. These findings suggest that *A. tricolor* exerts cardioprotective effects by mitigating oxidative stress, inflammation, and fibrosis, thereby highlighting its potential as a therapeutic agent for myocardial infarction, particularly in estrogen-deficient conditions. Further studies are warranted to elucidate the molecular mechanisms underlying these cardioprotective properties.[21]

Anti-melanin activity

The anti-melanin production effect of *A. tricolor* ethanolic extract was evaluated in melanoma cells. *A. tricolor* was found to inhibit both mushroom and cellular tyrosinase activities, with IC_{50} values of 242.2 ± 9.5 and 202.9 ± 11.6 µg/mL, respectively. Additionally, *A. tricolor* treatment reduced melanin production by approximately 30% and inhibited p38 MAPK phosphorylation at a concentration of 400 µg/mL. These findings suggest that the inhibition of tyrosinase activity by *A. tricolor* may significantly contribute to the reduction of melanin synthesis. The presence of high levels of phenolic compounds and anthocyanins in *A. tricolor* likely plays a significant role in this effect, as these compounds are known to possess tyrosinase-inhibitory properties. Furthermore, *A. tricolor* antioxidant activity, demonstrated through its DPPH radical scavenging and ROS suppression, further supports its potential to reduce melanin production by preventing oxidative stress. The downregulation of p38 MAPK phosphorylation by *A. tricolor* also suggests that its anti-melanin effects may involve the suppression of signaling pathways critical for melanogenesis. Overall, *A. tricolor* shows promising potential in inhibiting melanin production, which may be beneficial in addressing hyperpigmentation and related skin conditions. [22]

Anthelmintic activity

This study explored the anthelmintic potential of *A. tricolor* Linn using acetone, ethyl acetate, and ethanol as solvents to obtain various plant extracts. The extracts were analyzed for phytochemical content and tested for vermicidal activity against adult *Eisenia fetida* earthworms. Each extract displayed substantial anthelmintic activity, demonstrating dose-dependent effects on both paralysis and death of the worms when tested at concentrations of 10 to 30 mg/mL. In the bioassay, the acetone extract showed

the most promising anthelmintic efficacy, paralyzing the worms within 5 minutes and achieving lethality at 13 minutes when used at the highest concentration (30 mg/mL). The reference standard, albendazole, was outperformed by all extracts, highlighting *A. tricolor* as a potent anthelmintic agent. Normal saline was used as the control group. The results indicate that the acetone extract of *A. tricolor* holds potential as an effective vermicidal agent, likely attributed to its high content of glycosidic and phenolic compounds, as confirmed by preliminary phytochemical analyses. This study scientifically validates the traditional use of *A. tricolor* as a vermicidal agent and highlights its leaves as a promising source of active anthelmintic compounds.[23]

Antibacterial activity

The antibacterial activity of *A. tricolor* was evaluated for its potential as a biological pesticide. The study demonstrated that extracts from *A. tricolor* exhibited significant bacteriostatic effects against *Acidovorax avenae* subsp. *citrulli*, with the extracts causing visible distortion, deformation, and disintegration of bacterial cells. These changes in bacterial morphology suggest that *A. tricolor* extracts inhibit bacterial growth through structural damage. Metabolomics analysis revealed significant alterations in bacterial metabolites following treatment with *A. tricolor* extracts, indicating that the plant disrupts bacterial metabolism. Additionally, *A. tricolor* extracts were found to compromise bacterial cell membrane integrity, leading to leakage of intracellular substances, which further supports its bactericidal properties. The results demonstrate the potential of *A. tricolor* as a source of natural antibacterial agent.[24]

Anticancer activity

The anticancer activity of *A. tricolor* is attributed to its rich content of bioactive phytochemicals, including flavonoids, alkaloids, and saponins. Flavonoids play a crucial role in combating cancer by exhibiting strong antioxidant properties, inhibiting the proliferation of cancer cells, and inducing apoptosis. Alkaloids found in *A. tricolor* exhibit significant anticancer potential, playing a crucial role in the development of bioactive compounds with therapeutic applications. Similarly, saponins contribute to anticancer activity by inhibiting cancer cell proliferation, inducing apoptosis, and enhancing immune system responses. These findings suggest that *A. tricolor* holds promise as a natural source of anticancer agents, warranting further research to explore the underlying mechanisms and isolate specific active compounds.[25]

Anti-nociceptive and anti-inflammatory

The hydroalcoholic extract of *A. tricolor* was evaluated for its anti-nociceptive and anti-inflammatory activities. *A. tricolor* exhibited significant analgesic effects in the acetic acid-induced abdominal writhing test in mice, at doses of 200 and 400 mg/kg, highlighting its potent non-narcotic anti-nociceptive properties. However, in the hot plate test, which evaluates central analgesic effects, the extract did not exhibit notable activity. These findings suggest that the analgesic effects of *A. tricolor* are more pronounced in peripheral pain models. The anti-inflammatory activity of *A. tricolor* was evaluated using two well-established models: the carrageenan-induced rat paw edema test and the cotton pellet-induced granuloma test. In the carrageenan-induced paw edema model, the extract demonstrated a significant reduction in paw edema, indicating its ability to inhibit acute inflammation. *A. tricolor* demonstrated significant inhibition of paw edema, particularly during the late phase (3–5 hours). This late phase of inflammation is closely associated with neutrophilic infiltration and sustained prostaglandin production, indicating that *A. tricolor* may exert its anti-inflammatory effects by modulating the arachidonic acid pathway. Similarly, in the cotton pellet-induced granuloma test, *A. tricolor* showed a reduction in granuloma weight, further supporting its anti-inflammatory potential. This model reflects the proliferative phase of inflammation, characterized by fibroblast activity and collagen synthesis. By inhibiting these processes, *A. tricolor* highlights its ability to interfere with tissue proliferation and chronic inflammation. Overall, these results consistently indicate that *A. tricolor* possesses both anti-nociceptive and anti-inflammatory properties, making it a promising candidate for managing inflammatory conditions.[26]

Conclusion

A. tricolor is a nutritionally rich plant with remarkable therapeutic potential, offering benefits such as antimicrobial, hepatoprotective, neuroprotective, cardioprotective, anti-inflammatory, and anticancer effects. Its adaptability to diverse environments and economic viability make it an ideal functional food and a contributor to preventive health strategies. Future research should aim to isolate and study its bioactive compounds to maximize their medicinal applications.

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